UNITED STATES PATENT APPLICATION

OF

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FOR

SYSTEM AND METHOD FOR IDENTIFYING CONGESTED LINKS IN COMPUTER NETWORK

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By _____

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1   **FIELD OF THE INVENTION**

2   The invention relates generally to the field of digital data networks, and more particularly

3   to systems and methods for identifying which, if any, of the communication links used to transfer

4   message packets in respective networks are congested.

5   **BACKGROUND OF THE INVENTION**

6   Digital networks have been developed to facilitate the transfer of information, including data

7   and programs, among digital computer systems and other digital devices. Typically, a network

8   includes a plurality of switching nodes interconnected by communication links that are configured

9   to transfer information in the form of message packets. Problems arise if too many devices wish to

10   contemporaneously transfer information packets over paths that utilize the same communication link.

11   When that occurs, the switching node that transmits message packets over that communication link

12   can experience congestion in connection with that communication link. Congestion may lead to

13   unacceptably long times to transfer message packets, congestion in other communication links, and

14   may even require the switching node or nodes that are experiencing congestion to discard message

15   packets. Accordingly, it is desirable to be able to determine locations in a network at which

16   congestion occurs so that corrective action, such as increasing message packet transfer bandwidth,

17   re-routing of message transfer paths away from the points of congestion, and the like, can be

18   undertaken.

19   **SUMMARY OF THE INVENTION**

20   The invention provides a new and improved system and method for identifying congested

21   communication links in a digital data network.

1   In brief summary, the invention provides a congested link identification system configured
2   to be used in connection with a network for facilitating transfer of message packets among a plurality
3   of information utilization devices. The network comprises a plurality of switching nodes
4   interconnected by a plurality of communication links, at least some of the information utilization
5   devices being configured to transfer message packets thereamong over paths through the network,
6   with each path comprising at least one communication link. The congested link identification
7   system comprises a plurality of congestion detection agents and a congestion link identification
8   processor. Each congestion detection agent is associated with one of the information utilization
9   devices. Each congestion detection agent is configured to generate congested path information
10   indicating whether respective paths used by the information utilization device associated with the
11   respective congestion detection information are congested. The congestion link identification
12   processor is configured to process the congestion detection information generated by the congestion
13   detection agents to identify communication links that are congested.

14   In one embodiment, the congested link identification processor comprises a network
15   connectivity graph generation module, an edge link labeling module and a graph pruning module.
16   The network connectivity graph generation module is configured to generate a network connectivity
17   graph describing the topology of at least a portion of the network from the congested path
18   information, the network connectivity graph including a plurality of vertices each associated with
19   one of said switching nodes and edges each associated with one of said communication links. The
20   edge link labeling module is configured to label the edges in the graph, each edge being labeled as
21   being congested if the congested path information indicates that all of the paths that utilize the
22   communication link associated with that edge are congested, and otherwise labeling the edge not
23   congested. The graph pruning module is configured to prune the graph of edges that are labeled not
24   congested, the edges that are not pruned being congested.

1   BRIEF DESCRIPTION OF THE DRAWINGS

2   This invention is pointed out with particularity in the appended claims. The above and

3   further advantages of this invention may be better understood by referring to the following

4   description taken in conjunction with the accompanying drawings, in which:

5   FIG. 1 schematically depicts a digital data network for transferring information among a

6   plurality of information utilization devices, and further including a system for identifying congested

7   communication links, constructed in accordance with the invention;

8   FIG. 2 schematically depicts an illustrative network connectivity graph generated by the

9   congested communication link identification system for the network depicted in FIG. 1, which is

10   useful in understanding operations performed thereby in connection with detecting congested

11   communication links; and

12   FIG. 3 is a flow chart depicting operations performed by the congested communication link

13   identification system in connection with detecting congested communication links in the digital data

14   network depicted in FIG. 1.

15   DETAILED DESCRIPTION OF AN ILLUSTRATIVE EMBODIMENT

16   FIG. 1 schematically depicts a digital data network 10 for transferring information among

17   a plurality of information utilization devices 11(1) through 11(N) (generally identified by reference

18   numeral 11(n), and further including a system for identifying congested communication links

19   constructed in accordance with the invention. With reference to FIG. 1, the digital data network 10

20   includes a plurality of switching nodes 12(1) through 12(M) interconnected by communication links,

21   generally identified by reference numeral $13(m_1)(m_2)$. Each information utilization device 11(n) is

1   also connected to one or more switching nodes 12(m) to enable them to transmit and/or receive

2   information over the network.

3   The information utilization devices 11(n) may comprise any type of devices that may need

4   to transmit or receive information over the network, including, for example, personal computers,

5   computer workstations, mini- and mainframe computers. In addition, the information utilization

6   devices 11(n) may comprise other types of devices, including, for example, network printers for

7   providing hardcopy output, video display devices for retrieving and displaying video images, sensors

8   for providing information for, for example, scientific analysis, and any other type of device that may

9   generate or need to utilize digital information.

10   Communication links $13(m_1)(m_2)$ may comprise any type of communication link that can

11   transfer information in a digital data network. The communication links $13(m_1)(m_2)$ preferably

12   transfer information bidirectionally, and typically will comprise separate links $14(m_1)(m_2)$ and

13     $14(m_2)(m_1)$, as shown specifically for communication link 13(8)(9). That is, communication link

14     $13(m_1)(m_2)$ includes a link $14(m_1)(m_2)$ for transferring information from switching node $12(m_1)$ to

15   switching node $12(m_2)$, and a link $14(m_2)(m_1)$ for transferring information from switching node

16     $12(m_2)$ to switching node $12(m_1)$.

17   As is conventional, the information utilization devices 11(n) transfer information through the

18   network in the form of message packets using any convenient communication protocol. The

19   protocol may enable the information utilization devices 11(n) to transfer information using a "peer-

20   to-peer" methodology or a "client-server" methodology, or both. Typically in a "peer-to-peer"

21   protocol, any information utilization device 11(n) will transfer a message packet to any other

22   information utilization device.

23   On the other hand, in a client-server protocol, generally one or more of the information

24   utilization devices are designated as servers and others will be designated as clients. Servers

25   typically store information that may be downloaded and used by the clients in their processing or

1   other operations. In that operation, a client will generate one or more message packets requesting

2   downloading of particular items of information, and transmit the message packet(s) to the particular

3   server(s) on which the information items are stored. The server(s), after receiving the message

4   packet(s) containing the download request, will process the request to obtain the requested

5   information items from storage, load them into one or more message packets and transmit the

6   message packet(s) to the client for utilization thereby.

7   The clients can also upload information to the servers for storage, and, in that operation, a

8   client will generate one or more message packets storage of respective items of information by the

9   server, the message packets including the information items to be stored, and transmit the message

10   packet(s) to the particular server(s) on which the information items are to be stored. After receipt

11   of the message packet(s), the server will store the information items. The clients may later download

12   the uploaded information. The downloading of information stored on the servers may be restricted

13   to, for example, the particular computers that uploaded the information or to particular users of those

14   computers. Alternatively, any computer or user may download information stored on the servers.

15   Transferring information according to a client-server methodology facilitates ready sharing of data

16   among, for example, computers connected to the network and can allow users who have permission

17   to access particular items of information to download the information to various computers that they

18   may be using.

19   As noted above, the information is transferred in the form of message packets. An

20   information utilization device $11(n')$, as a source information utilization device $11(n_S)$, will generate

21   a message packet for transfer to another information utilization device $11(n'')$, as a destination

22   information utilization device $11(n_D)$, and transmit the message packet to a switching node $12(m_1)$.

23   If the switching node $12(m_1)$ is also connected to the destination information utilization device

24    $11(n_D)$, the switching node $12(m_1)$ can transfer the message packet to the information utilization

25   device $11(n_D)$. However, if the switching node $12(m_1)$ is not connected to the destination

26   information utilization device $11(n_D)$, it will transfer the message packet to another switching node

1   12(m_2), which will perform the same operations as switching node 12(m_1). Each switching node

2   12(m_1), 12(m_2), 12(m_3),... that receives the message packet will perform the same operations, until

3   the message packet reaches a switching node 12(m_X) that is connected to the destination information

4   utilization device 11(n_D), that switching node 12(m_X) will transfer the message packet to the

5   destination information utilization device 11(n_D). The switching node or sequence of switching

6   nodes 12(m_1), 12(m_2),... from the source information utilization device 11(n_S) to the destination

7   information utilization device 11(n_D) defines the path for message packets transferred from the

8   source information utilization device 11(n_S) to the destination information utilization device 11(n_D).

9   The switching node or sequence of switching nodes over which the message packet is transferred

10   will typically be selected so that the path will contain the minimum or, at least a relatively small,

11   number of switching nodes 12(m).

12   Each path over which an information utilization device 11(n') transmits message packets to

13   another information utilization device 11(n") may be associated with a "connection," which, in turn,

14   will be associated with a connection identifier. In that case, each message packet will include the

15   connection identifier for the connection associated with the path over which the message packet is

16   to be transferred. Each switching node 12(m), when it receives a message packet, can identify the

17   communication link over which it is to transmit a message packet that it receives using the

18   connection identifier in the respective message packet.

19   It will be appreciated that an information utilization device 11(n') may operate as both a

20   source information utilization device 11(n_S), to transmit information to other information utilization

21   devices 11(n"), 11(n'''),... and a destination information utilization device 11(n_D) to receive

22   information from other information utilization devices 11(n"), 11(n'''),.... Some information

23   utilization devices 11(n"") may, on the other hand, operate only as source information utilization

24   devices 11(n_S) or destination information utilization devices 11(n_D).

25   In any case, the switching nodes 12(m) will perform the operations described above for each

26   message packet transferred between each pair of source and destination information utilization

1   devices 11(n_S) and 11(n_D). It will be appreciated that at least portions of paths between at least some

2   pairs of source and destination information utilization devices 11(n_S) and 11(n_D) will overlap, such

3   that, for example, a switching node 11(n') may contemporaneously receive several message packets

4   over respective ones of the communication links 13 connected thereto, for transmission over the

5   same communication link. In that case, since the switching node 11(n') can only transmit one

6   message packet at a time over a communication link 13, it will need to buffer at least some of the

7   message packets while it transfers others over the communication link. Accordingly, depending on

8   the rate at which a switching node 11(n') contemporaneously receives message packets for transfer

9   over the same communication link, congestion can develop as the switching nodes's buffer fills up

10 and the switching node either has to discard message packets or attempt to regulate the flow of

11 message packets thereto for transfer over the respective communication link. Congestion can, in

12 addition to possibly leading to discarding of message packets, also lead to undesirably long delays

13 in delivering message packets, which can, for example, unduly delay processing in the case of

14 computers, unduly delay production of hardcopy output in the case of network printers, cause

15 interruptions in display in the case of video displays, and so forth. Accordingly, if congestion

16 develops, it is desirable to identify where the congestion is located to determine whether corrective

17 action, such as routing, increasing bandwidth or the like, can be undertaken, if so desired.

18   The arrangement depicted in FIG. 1 is provided with a congested communication link

19 identification system for identifying which, if any, of the communication links 13 are exhibiting

20 congestion. The congested communication link identification system includes, at each information

21 utilization device 11(n), an associated congestion detection agent 20(1) through 20(N) (generally

22 identified by reference numeral 20(n)) and a congested link identification processor 21. Each

23 congestion detection agent 20(n), which may be embodied in a software program running on the

24 respective information utilization device 11(n). Each congestion detection agent 20(n') generates

25 congestion information indicating whether the associated information utilization device 20(n') is

26 experiencing congestion in connection with message packets received from or transmitted to other

27 information utilization devices 20(n"), 20(n'''),... (n", n'''... ≠n') over respective paths thereto. The

1   congested link identification processor 21 receives the congestion information from the congestion

2   detection agents 20(n) and processes it to identify communication links 13, if any, that are congested.

3   As noted above, each congestion detection agent 20(n') generates congestion information

4   indicating whether the associated information utilization device 11(n') is experiencing congestion

5   in connection with message packets received from or transmitted to other information utilization

6   devices 20(n"), 20(n'"),... (n", n'"...≠n') over respective paths thereto. Each congestion detection

7   agent 20(n') can use any convenient methodology to determine whether the associated information

8   utilization device 11(n') is experiencing congestion, including, for example, whether message

9   packets transmitted to the associated information utilization device 11(n') from a respective other

10   information utilization device 11(n"), 11(n'"),... are unduly delayed, taking into account the number

11   of switching nodes 12(m) along the path from the other information utilization device 11(n"),

12   11(n'"),... to the information utilization device 11(n'). In that operation, the congestion detection

13   agent 20(n') can, for example, determine for each message packet the time period between the time

14   at which the message packet was generated, as indicated by a time stamp provided in respective

15   message packets, and the time at which the message packet is received.

16   If the time period is below a predetermined threshold value for a particular message packet,

17   the threshold value preferably taking into account the number of switching nodes 12(m) along the

18   path from the other information utilization device 11(n"), 11(n'"),... to the information utilization

19   device 11(n'), the congestion detection agent 20(n') can determine that that message packet had not

20   experienced congestion. In that case, if the congestion detection agent 20(n') had not previously

21   marked the path from the other information utilization device 11(n"), 11(n'"),... to the information

22   utilization device 11(n') as being congested, it can mark the path as not being congested. On the

23   other hand, if the time period is above the predetermined threshold value, the congestion detection

24   agent 20(n') can determine that that message packet had experienced congestion, and mark the path

25   from the other information utilization device 20(n"), 20(n'"),... to the information utilization device

26   11(n') associated with the congestion detection agent 20(n') as being congested. It will be

1   appreciated that, with this methodology, determinations as to whether a path is congested will be

2   made by the congestion detection agents 20(n) associated with information utilization devices 11(n)

3   that operate as destination information utilization devices 11(n_D)

4   Alternatively or in addition, congestion detection agents 20(n) can determine that congestion

5   arises in connection with a path if its associated information utilization device 11(n) receives a

6   notification thereof. If, for example, a switching node 12(m), when it determines that a congestion

7   condition exists in connection with communication link over which it is to transmit message packets,

8   it can identify all of the connections for which that communication link forms part of the path, and

9   transmit congestion notifications to the information utilization devices 11(n) which comprise source

10   information utilization devices 11(n_S) that transmit message packets over those connections.

11   Alternatively, the switching node 12(m), when it determines that the congestion condition exist,

12   instead of transmitting congestion notifications to all such source information utilization devices

13   11(n_S), it can transmit the congestion notifications to each such source information utilization device

14   11(n_S) when it receives a message packet therefrom.

15   The congestion detection agent 20(n') does not initially mark paths between its associated

16   information utilization device 11(n') and the other information utilization devices 11(n"), 11(n'''),...

17   as being congested, because there may be no message packets transferred over some paths. In

18   addition, after the congestion detection agent 20(n') has marked a path as being congested, it will not

19   thereafter change the mark to indicate that the path is not congested for reasons that will be made

20   clear below.

21   The congestion detection agents 20(n) can operate over, for example, a predetermined time

22   period. At some point in time, the congestion detection agents 20(n) will provide congestion

23   information, which will be referred to as the "congested path information," to the congested link

24   identification processor 21, including the identifications of the paths that they have marked as being

25   not congested and the paths that they have marked as being congested. The congested link

26   identification processor 21, after receiving the congested path information, will process it to attempt

1   to identify which communication links, if any, are congested. It will be appreciated that the

2   congested path information identifies paths, rather than communication links, that are marked as

3   being congested or not congested, and the congested link identification processor 21 processes the

4   congested path information to identify which, if any, of the communication links 13 are congested.

5   Generally, in that operation, the congested link identification processor 21 will identify congested

6   communication links by determining the communication links, if any, for which congestion

7   detection agents 20(n) associated with all of the information utilization devices 11(n) that have

8   connections over the respective communication links report that they are congested. If at least one

9   congested detection agent 20(n) reports that a path over one or more communication links is not

10   congested, the congested link identification processor 21 will determine that none of the

11   communication links that form the path are congested.

12   An example will help understand now the congested link identification processor 21

13   identifies congested communication links. With continued reference to FIG. 1, assume, for example,

14   that the following paths are marked congested:

15   (i)   one or more paths for transferring message packets from switching node 12(1),

               through switching nodes 12(8) and 12(9), to switching node 12(4);

17   (ii)   one or more paths for transferring message packets from switching node 12(1),

18   through switching nodes 12(8) and 12(9), to switching node 12(5);

19   (iii)   one or more paths for transferring message packets from switching node 12(2)

20   through switching node 12(8) and 12(9), to switching node 12(4);

21   (iv)   one or more paths for transferring message packets from switching node 12(2)

22   through switching node 12(8) and 12(9), to switching node 12(5);

23   (v)   one or more paths for transferring message packets from switching node 12(7)

24   through switching node 12(8) and 12(9), to switching node 12(3);

1   (vi)   one or more paths for transferring message packets from switching node 12(7)

2   through switching node 12(8) and 12(9), to switching node 12(4); and

3   (vii)   one or more paths for transferring message packets from switching node 12(6)

4   through switching node 12(8) and 12(9), to switching node 12(3).

5   On the other hand, assume that the following paths are marked not congested:

6   (a)   one or more paths for transferring message packets from switching node 12(1)

7   through switching node 12(8) to switching node 12(6);

8   (b)   one or more paths for transferring message packets from switching node 12(2)

9   through switching node 12(8) to switching node 12(6);

10   (c)   one or more paths for transferring message packets from switching node 12(2)

11   through switching node 12(8) to switching node 12(7);

12   (d)   one or more paths for transferring message packets from switching node 12(6)

13   through switching node 12(8) to switching node 12(2);

14   (e)   one or more paths for transferring message packets from switching node 12(7)

15   through switching node 12(8) to switching node 12(2);

16   (f)   one or more paths for transferring message packets from switching node 12(3)

17   through switching node 12(9) to switching node 12(5);

18   (g)   one or more paths for transferring message packets from switching node 12(5)

19   through switching node 12(9) to switching node 12(3); and

20   (h)   one or more paths for transferring message packets from switching node 12(5)

21   through switching node 12(9) to switching node 12(4).

1   In that case, it will be apparent that the link 14(8)(9) for transferring message packets from switching

2   node 12(8) to switching node 12(9) is congested. This follows from the fact that:

3   (A)   the paths marked as being congested indicate that one or more of the following links

4   may be congested:

5   (I)   the link 14(1)(8) from switching node 12(1) to switching node 12(8)

6   (reference (i) above);

7   (II)   the link 14(2)(8) from switching node 12(2) to switching node 12(8)

8   (reference (iii) and (iv) above);

9   (III) the link 14(6)(8) from switching node 12(6) to switching node 12(8)

10   (reference (vii) above);

11   (IV)   the link 14(7)(8) from switching node 12(7) to switching node 12(8)

12   (reference (v) and (vi) above);

13   (V)   the link 14(8)(9) from switching node 12(8) to switching node 12(9)

14   (reference (i) through (vii) above);

15   (VI)   the link 14(9)(3) from switching node 12(9) to switching node 12(3)

16   (reference (v) and (vii) above);

17   (VII) the link 14(9)(4) from switching node 12(9) to switching node 12(4)

18   (reference (i) and (iii) above);

19   (VIII) the link 14(9)(5) from switching node 12(9) to switching node 12(5)

20   (reference (ii) and (iii) above);

21   (B)   However, the congested path information indicates that the following communication

22   links are not congested:

1   (I)   the link 14(1)(8) from switching node 12(1) to switching node 12(8)

2   (reference (a) above);

3   (II)   the link 14(2)(8) from switching node 12(2) to switching node 12(8)

4   (reference (b) and (c) above);

5   (III)   the link 14(6)(8) from switching node 12(6) to switching node 12(8)

6   (reference (d) above);

7   (IV)   the link 14(7)(8) from switching node 12(7) to switching node 12(8)

8   (reference (e) above);

9   (VII)   the link 14(9)(3) from switching node 12(9) to switching node 12(3)

10   (reference (f) above);

11 (VIII) the link 14(9)(4) from switching node 12(9) to switching node 12(4)

12   (reference (h) above); and

13 (IX)   the link 14(9)(5) from switching node 12(9) to switching node 12(5)

14   (reference (g) above);

15 leaving (V), the link 14(8)(9) from switching node 12(8) to switching node 12(9), as being

16 congested.

17   The congested link identification processor 21 processes the congested path information

18 received from the congestion detection agents 20(n) in three steps, namely:

19 (1)   a network connectivity graph generation step (step 100, FIG. 3), in which the

20   congested link identification processor 21 generates a network connectivity graph

21   describing the topology of the network 10 from the congested path information;

1   (2)   an edge link labeling step (step 101) in which the congested link identification

2   processor 21 labels the links ("edges") in the graph; and

3   (3)   a graph pruning step (step 102), in which the congested link identification processor

4   prunes the graph of edges associated with links that are not congested.

5   At the end of the graph pruning step (step 102), the only edges remaining will be the edges that are

6   associated with links that are congested.

7   In the network connectivity graph generation step, the congested link identification processor

8   21 generates the network connectivity graph to include a plurality of vertices (corresponding to

9   switching nodes) and edges (corresponding to the links $14(m_1)(m_2)$), generally with the same

10   topology as the network 10 to the extent that the congestion detection agents 20(n) report links

11   $14(m_1)(m_2)$ that are congested and links that are not congested. Generally, that will be expected to

12   be all of the links, but if, in fact, a link is not used for any paths over which message packets are

13   transferred while the congestion detection agents 20(n) are accumulating the congested path

14   information, those links will not be represented in the network connectivity graph generated by the

15   congested link identification processor 21. For example, if, while the congestion detection agents

16   20(n) are gathering the congested path information, no message packets are transmitted over the link

17   14(1)(2) or 14(2)(1) of communication link 13(1)(2), during the network connectivity generation

18   step, the network connectivity graph will not include an edge associated with the link or

19   communication link. Similarly, if, while the congestion detection agents 20(n) are gathering

20   congested path information, no message packets are transferred through a particular switching node

21   12(m), the congested link identification processor 21 will not provide a vertex associated with the

22   particular switching node 12(m).

23   FIG. 2 depicts an illustrative network connectivity graph 30 generated by the congested link

24   identification processor 21 during the network connectivity graph generation step. In with the

25   network 10 described above in connection with FIG. 1, and assuming that the only message packet

1   traffic is that described above, the congested link identification processor 21 will generate a graph

2   as depicted in FIG. 2. With reference to FIG. 2, the illustrative network connectivity graph includes

3   a plurality of nodes 31(1) through 32(9) (generally identified by reference numeral 32(m))

4   interconnected by edges $33(m_1)(m_2)$. The edges interconnect the respective nodes in the same

5   pattern as the communication links $13(m_1)(m_2)$ interconnect the switching nodes 12(m), with the

6   exception that there are no edges for communication links $13(m_1)(m_2)$ for which there is no

7   congested link information. Accordingly, there are no edges for communication links 13(1)(7),

8   13(1)(2), 13(6)(7), 13(5)(6), 13(2)(3) and 13(3)(4). As with the communication links, each edge

9   $33(m_1)(m_2)$ may actually consist of two directional edges $34(m_1)(m_2)$ each relating to the respective

10 direction of the links $14(m_1)(m_2)$ comprising a communication link $13(m_1)(m_2)$; in that case, the

11 directional edge 34(8)(9) will be provided in the network connectivity graph 30, but not a directional

12 edge 34(9)(8), since there is no congested link information for that directional edge.

13 In the edge link labeling step, the congested link identification processor 21 labels each edge.

14 In one embodiment, the congested link identification processor labels each edge with one of two

15 labels, namely, a (+) if at least some of the congested path information for the edge indicated that

16 the edge was not congested, or a (-) if all of the congested link information for the edge indicated

17 that the edge was congested. Each direction edge $34(m_1)(m_2)$ will be labeled independently.

18 Accordingly, since, for all of the direction edges $34(m_1)(m_2)$ in the graph, except for direction edge

19 34(8)(9), congested path information from at least one congestion detection agent 20(n) indicates

20 that the links $14(m_1)(m_2)$ associated with the edges $34(m_1)(m_2)$ are not congested, those edges will

21 be associated with the (+) label. On the other hand, for direction edge 34(8)(9), all of the congested

22 path information from the congestion detection agents 20(n) related to that edge indicates that the

23 edge is congested, and so that edge will be associated with the (-) label.

24 Finally, in the graph pruning step, the congested link identification processor 21 will prune

25 the network connectivity graph to identify the direction edge or edges $34(m_1)(m_2)$ that are congested,

26 if any. In that operation, the congested link identification processor 21 selects one of the vertices

1   32(m) as a root of a tree formed with the other vertices, and performs a depth-first search from the

2   vertices that form leaves of the tree up to the root. As the congested link identification processor 21

3   proceeds up the tree, it will eliminate edges that are labeled (+). If the congested link identification

4   processor 21 reaches an edge that is labeled (-), it will stop and select another leaf vertex 32(m) from

5   which to start a search, and repeat these operations. After the congested link identification processor

6   21 has performed searches in connection with all of the leaf vertices, it can select another vertex as

7   root and repeat the operations. After all of the edges that are labeled (+) have been removed, the

8   edges that are labeled (-) will remain and the congested link identification processor 21 will identify

9   those, if any, as being congested.

10   Using the illustrative network connectivity graph 30 depicted in FIG. 2, if, for example, the

11 congested link identification processor 21 initially selects vertex 32(8) as the root of the tree, it can

12 start with, for example, vertex 32(3) as leaf vertex. In that case, since edge 33(3)(9) is labeled (+),

13 it will move up to vertex 32(9) and, since edge 33(3)(9) is labeled (+), remove the edge 33(3)(9).

14 Since the edge 34(8)(9) is labeled (-), it will stop at that edge. Thereafter, if the congested link

15 identification processor 21 selects vertex 32(4) as leaf, it will repeat the operations described above

16 in connection with vertex 32(3). That is, since edge 34(9)(4) is labeled (+), it will move to vertex

17 32(9) and remove the edge 34(9)(4) and, since edge 34(8)(9) is labeled (-), stop at vertex 32(9). The

18 congested link identification processor 21 can repeat these operations for all of the leaf vertices and,

19 when complete, the only edge remaining will be edge 34(8)(9), which, as noted above, is associated

20 with the direction link 14(8)(9). As noted above, that direction link 14(8)(9) is the congested link,

21 and the congested link identification processor 21 will identify it as such.

22   The invention provides a number of advantages. In particular, the invention provides an

23 arrangement for identifying congested communication links in a network based on processing in

24 connection with congestion information indicating whether certain paths, such as confections or

25 connections, through the network over which message packets are transferred are congested or are

26 not congested. Since the arrangement makes use of congestion information for respective paths in

1   the network, it will be appreciated that the arrangement can identify congested links in complicated

2   networks without requiring information from the switching nodes 12(m) themselves.

3   It will be appreciated that a number of modifications may be made to the arrangement as

4   described above. For example, although the information utilization devices 11(n) have been

5   described as individual devices each connected individually to a switching node 12(m), it will be

6   appreciated that an information utilization device 11(n) may comprise a local area network or sub-

7   network, a connection to a wide area network, or any other arrangement that can transmit message

8   packets to and/or receive message packets from a switching node 12(m).

9   In addition, it will be appreciated that the communication links $13(m_1)(m_2)$ may comprise

10   any convenient medium for transferring message packets, including, but not limited to, wires, optical

11   fibers and the like.

12   Furthermore, it will be appreciated that the congested link identification arrangement as

13   described above can partition the congested link information according to time period, including,

14   for example, particular times of day and particular days of the week, and determine whether

15   particular links are consistently congested at particular times of day, particular days of the week, and

16   so forth. This may occur if, for example, a number of people in an organization are engaged in

17   performing a particular type of operation, in connection with information stored in particular

18   locations. By identifying particular communication links that are congested during particular time

19   periods a system administrator may be able to, for example, enable certain paths (that is,

20   connections) that use the congested communication links to be re-routed over other communication

21   links to alleviate the congestion.

22   Furthermore, it will be appreciated that the congested link identification processor 21 can use

23   any conventional methodology in connection with the individual steps described above in connection

24   with FIG. 3.

1   It will be appreciated that a system in accordance with the invention can be constructed in

2   whole or in part from special purpose hardware or a general purpose computer system, or any

3   combination thereof, any portion of which may be controlled by a suitable program. Any program

4   may in whole or in part comprise part of or be stored on the system in a conventional manner, or it

5   may in whole or in part be provided in to the system over a network or other mechanism for

6   transferring information in a conventional manner. In addition, it will be appreciated that the system

7   may be operated and/or otherwise controlled by means of information provided by an operator using

8   operator input elements (not shown) which may be connected directly to the system or which may

9   transfer the information to the system over a network or other mechanism for transferring

10   information in a conventional manner.

11   The foregoing description has been limited to a specific embodiment of this invention. It will

12   be apparent, however, that various variations and modifications may be made to the invention, with

13   the attainment of some or all of the advantages of the invention. It is the object of the appended

14   claims to cover these and such other variations and modifications as come within the true spirit and

15   scope of the invention.

16   What is claimed as new and desired to be secured by Letters Patent of the United States is: